Pergamon

Marine Pollution Bulletin Vol. 38, No. 5, pp. 345–355, 1999

Printed in Great Britain
0025-326X/99 $ – see front matter

PII: S0025-326X(99)00002-8

A Global Assessment of Human Effects on Coral Reefs

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Coral reefs have been used by humans as recreation areas and as a source of food and other products for thousands of years. The effects of humans on coral reefs are not well understood, especially on a regional or global scale. A special survey protocol called "Reef Check" was designed to be used by volunteer recreational divers, trained and led by marine scientists, and based on the use of high value, easily identified indicator organisms. During a period of 2.5 months, a global survey of over 300 reefs in 31 countries and territories indicates that few reefs remain unaffected by man, even very remote sites. Overfishing has reduced fish and invertebrate indicator organisms to low levels at most reefs, including those within marine protected areas. The ratio of live to dead coral cover was higher in the Red Sea than in other regions, indicating that reef corals are in the best condition there. In future years, by increasing the number of reefs and the frequency of surveys, the Reef Check program could provide a valuable method to detect broad-brush changes on a local, regional and global scale, as well as increasing public support for coral reef conservation.

Keywords: reefs; fisheries; marine ecology; global survey; human effects; conservation.

For thousands of years, humans have gathered and fished for coral reef organisms for use as curios, jewelry, and food. More recently, exploitation of reefs has increased as novel medicinal compounds have been extracted and as reef-related tourism has expanded. According to media reports, anecdotal accounts from scuba divers and published work of marine scientists from diverse locations around the world, increasing populations of humans have been damaging coral reefs at an unprecedented rate (Luchavez and Alcala, 1988; Wilkinson *et al.*, 1993; Munro and Munro, 1994; Grigg and Birkeland, 1997). Despite the ecological and economic importance of coral reefs, we have a poor understanding of how this ecosystem responds to human activities, particularly on a regional or global scale.

The 1993 Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History held at the University of Miami was a critical turning point in raising awareness among coral reef scientists about the need for a global assessment of coral reef health. Participants concluded that, "The data base for evaluating the condition of the world's reefs is quite inadequate." The reasons: too few coral reef scientists who spend too little time on reefs, and who use dozens of different methods to study diverse research topics – many unrelated to reef health. There are few cases of long-term studies of the same reef, and the use of one method to study many reefs is rare. The Colloquium participants concluded that, "There is an urgent need to provide a comprehensive assessment of reefs ..." A new approach was needed that would provide a sufficient "snapshot" of information about an individual reef to judge its status, and would allow each reef to be compared with others in the region and around the world on an annual basis. Many traditional studies of reefs have been designed with a relatively narrow focus on either fish or hard coral ecology, and have not captured sufficient information about a broad suite of reef organisms to allow an interpretation of reef health. "Coral reef health" is a general concept that refers to a balance in the ecosystem that may be shifted by e.g., disease or human activities. The present survey attempts to define objective measures of reef health based on the numbers of indicator organisms and other parameters affected by human activities.

Methods

In 1996, I designed a protocol to rapidly carry out the first global survey of coral reefs. The draft protocols were posted on the NOAA coral listserver in late 1996 and criticism was invited. Following revision of the protocols, a global survey program called "Reef Check" was advertised on the listserver, and about 40 pages of detailed instructions were placed on a website (www.ust.hk/~webrc/ReefCheck/reef.html) along with an invitation to form survey teams. The basic concept was to create an international network of national, regional and local coordinators who would be responsible for all aspects of the surveys in their chosen area. All surveys would be conducted using one set of methods during a period of 2.5 months and the data submitted to the coordinating office at the Hong Kong University of Science and Technology.

Reef health indicators

The framework for the survey methods was modeled after existing methods, such as (English *et al*., 1997). A major difference, however, was that 25 worldwide and regional "health indicators" were initially chosen to provide information about the effects of human activities such as cyanide fishing, aquarium fish collection and harvesting of invertebrates. Primary criteria for selecting "indicators" were: (1) ease of field identification, (2) high information content regarding reef health with respect to anthropogenic effects such as pollution or direct harvest, and (3) a broad geographic distribution. For several indicators, higher taxonomic categories such as families were used, rather than species, to ensure accurate identification by non-specialists. Species were used only when they could be positively identified due to a distinctive shape and color. Edible indicators also generally have a high market value. For example, spiny lobster of the family Palinuridae, and the grouper family Serranidae were chosen to be two of the eight worldwide indicators. For the purpose of selecting regional indicators, the world's oceans were divided into the Indo-pacific, Red Sea and Caribbean regions. Due to Hawaii's unique fish fauna, several different indicators were needed, therefore Indo-pacific regional analyses for fish do not include Hawaiian data. An example of an Indo-pacific regional indicator is the distinctive humphead wrasse *Cheilinus undulatus*, a cyanide fishing indicator. This species is the preferred fish in restaurants in Hong Kong and southern China where they sell for US$100 per kg. To supply this market, diving fishermen throughout the region use sodium cyanide to stun and capture live humpheads, the bigger the better (Johannes and Riepen, 1995). The full list of coral reef health indicators used in the survey is found in Table 1.

TABLE 1

Reef check indicator organisms for overfishing (OF), dynamite fishing (DF), cyanide fishing (CF), aquarium fish fishing (AF), pollution (PL) and curio collection (CR).

Organism	Indicator for					
	OF	DF	CF	AF	PL	CR
World						
Lobster	x					
Grouper (>30 cm)	x	x	x			
Fleshy algae					x	
Hard coral				x		x
Dead coral		x			x	
Sponge					x	
Butterfly fish				x		
Sweetlips – Haemulidae	x	x	x	x		
Indo-pacific only						
Barrimundi cod (*Cromileptes altivelis*)	x	x	x			
Humphead wrasse (*Cheilinus undulatus*)	x	x	x			
Bumphead parrotfish (*Bolbometopon muricatum*)	x	x	x			
Giant clams (*Tridacna* spp.)	x					x
Trochus shells (*Trochus niloticus*)	x					
Edible holothurians (4 species)	x					
Crown of thorns starfish (*Acanthaster planci*)					?	
Triton shell (*Charonia tritonis*)						x
Caribbean only						
Nassau Grouper (*Epinephalus striatus*)	x					
Snapper – Lutjanidae	x					
Parrotfish (>20 cm)	x					
Barracuda (>1 m)	x					
Queen conch (*Strombus gigas*)	x					x
Helmet conch (*Cassis madagascariensus*)	x					x

Site selection

Site selection was based on the goal of testing the null hypothesis that reefs still exist that are not affected significantly by human activities. Teams were instructed to survey outer slopes on exposed reefs that were considered to be the 'best' sites in their area – those believed to be least affected by human activities and having the highest percentage of the seabed covered by living hard coral and the highest populations of indicator fish and other invertebrates. Thus the surveys were intentionally biased towards reefs in relatively good condition. Detailed questions about the type of reef were included so that post-processing could take such differences into account.

Survey protocol

The protocol included collection of four types of data: a site description; a fish survey, an invertebrate survey and a substrate survey. The site description included 37 questions about the biophysical aspects of each reef, as well as socioeconomic descriptors of human activities in the area, and space for anecdotal and historical background information. The reef sampling design was based on surveys of two depth contours, 3 and 10 m. At each depth, one or more survey lines (transects) were placed along the reef contour to obtain a total length of 100 m. The fish survey was carried out first. Fish indicator taxa were recorded along four 20 m long, 5 m wide belt transects (separated by 5 m gaps) for a survey area of 400 m^2 at each depth (3 and 10 m). After the transects were deployed, the fish survey was delayed for 15 min to allow the fish to recover from any disturbance by divers. Fish were recorded within the belt transect for a period of 3 min at 5 m intervals. In some locations, coral reef was only found at one of the two depths – so only one contour was surveyed. For some fish, size limits (see Table 1) were used to limit the work such that a team of four divers could complete one survey per day, and to focus data collection on the fish sizes targeted by fishermen e.g., only grouper larger than 30 cm length were recorded. The same belt transect was then used for the invertebrate survey. Following the invertebrate survey, the four 20 m long segments were point-sampled at 0.5 m intervals and substrate type was recorded using a list of 10 possible choices: live hard coral, dead coral, soft coral, fleshy seaweed, sponge, rock, rubble, sand, silt/clay and other. The definition for dead coral was targeted at coral killed within the past one year while the definition for fleshy seaweed excluded coralline algae.

The data were recorded on pre-formatted slates and were checked in the field by the team scientist. The data were then transferred to automated spreadsheets (embedded macros calculated means and standard deviations) that had been distributed by FTP or e-mail. As part of the quality control system, these sheets were then submitted electronically to headquarters for another round of error checking prior to analysis. Queries were sent to team scientists regarding any questionable or missing data. High quality, partial data sets e.g., coral cover only were accepted.

Teams

The first global survey of coral reefs was carried out by teams of recreational divers trained and led by marine scientists during the period between 14 June and 31 August, 1997 at 315 reef sites in 31 countries and territories as shown in Table 2. A rigorous data checking system was used to avoid errors at each stage of data collection and transfer. Teams were able to download identification photos, laminate them and carry them underwater. Of the 75 team leaders, 58% hold a PhD or Master's degree in biology and all were experienced in conducting tropical marine surveys. Due to the large number of sites and circum-tropical distribution, a large map is needed to distinguish individual sites clustered in areas such as the Red Sea, hence none is given here. An indicative map is given on the Reef Check website. Due to some incomplete data sets, not all sites could be included in each analysis therefore the "N" for each analysis is given in the figure legend.

Results and Interpretation

Lobster

The results showed very low numbers of most high-value indicator organisms. Of the worldwide indicators, lobsters were rare, and none was recorded at 85% of reefs surveyed (Fig. 1A). In the Indo-pacific region, out of 169 reefs checked, only 33 lobsters were found, and 11 of these were recorded at one reef in an Indonesian marine reserve. Lobsters were more common in the Caribbean while none were recorded in the Red Sea. It is not considered likely that many lobsters were missed as the protocol requires searching crevices. Although lobsters generally hide in holes by day and feed at night, they are easily observed during the day due to their long antennae which typically extend outside. Anecdotal reports suggest that lobsters used to be abundant on coral reefs everywhere. In the 1950s, a few hours of net fishing on Florida reef flats could yield up to 500 kg of lobster (Davis and Dodrill, 1989). In the early 1970s, lobster were still sufficiently abundant in the same area that a few hours of lobster diving could yield 50 kg (personal observation). While the survey results do not mean that lobsters are nearly extinct on coral reefs, they do suggest that the well-documented major reduction in lobster populations on shallow Florida reefs (Davis and Dodrill, 1989) over the past 50 yr probably has been replicated throughout the tropics.

Grouper

Grouper (>30 cm) are heavily fished throughout the world using a variety of methods including poison and blast-fishing (Johannes and Riepen, 1995), and none was reported at 31% of the study reefs, with small numbers at most. Grouper were more common in the Red Sea and Indo-pacific than in the Caribbean where there are fewer species. A total of more than 20 large grouper were recorded at two sites in the remote Maldive Islands, at three sites in the Red Sea and 4 sites in Palau, where no poison or dynamite fishing has occurred (Fig. 1B). Although some fishing probably affected these latter reefs in the past, the "high" numbers of grouper recorded may serve as a temporary surrogate baseline in the absence of baseline data on unfished reefs from different parts of the world. In the Caribbean, the highly prized and previously common Nassau grouper was found at only 7 of 54 sites surveyed (a total of 15 fish). It is recognized that even without fishing, there is much natural inter-and intra-reef variation in the population density of reef organisms including fish (Williams, 1991). However, the mean abundance of medium-sized grouper (<1 fish per reef) recorded from more than 270 of the world's 'best' reefs is low when compared with the surrogate baseline of about 20 fish per reef. The simplest explanation is that grouper have been fished out from shallow reefs on a global scale.

Haemulidae

The Indo-pacific and Red Sea results for sweetlips (Haemulidae) revealed a similar pattern, with a mean of zero or <1 fish per reef reported from most sites. In the Caribbean the Haemulidae are represented by grunts and margates. A mean of 2–10 fish per reef was reported from about 40% of Caribbean sites (Fig. 1C). In addition, a mean of >10 fish per reef was reported from more than 30% of the sites. While there are more species of Haemulidae in the Indo-pacific than in the Caribbean, it is likely that biological differences among different genera as well as different levels of fishing pressure are responsible for the greater abundance of Haemulidae in the Caribbean than in the other regions.

Butterflyfish

The results for butterflyfish (Chaetodontidae) were different from all other organisms, with clear regional

TABLE 2
Location and number of Reef Check survey sites.

Location	Total	Site number
American Samoa	1	1
Australia	15	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
Bahrain	1	17
Barbados	5	221, 222, 223, 224, 225
Belize	4	226, 227, 311, 312
Bonaire	1	228
British Virgin Islands	3	229, 230, 231
Brunei Darussalam	1	18
Colombia	3	232, 233, 239
Cuba	2	313, 314
Egypt	55	166, 167, 168, 169, 170, 171, 172, 173, 174, 175,1 76, 177,1 78, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220
Fiji	7	19, 20, 21, 22, 23, 24, 25
Florida	24	234, 235, 236, 237, 238, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258
Grand Cayman Island	1	259
Guam	1	26
Honduras	1	260
Hong Kong	5	27, 28, 29, 30, 31
Indonesia	26	32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57
Israel	1	165
Japan	2	58, 59
Malaysia	73	60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 307, 308, 309, 310
Maldives	30	110,111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139
Mexico	7	261, 262, 263, 264, 265, 266, 267
Mozambique	1	140
New Caledonia	3	141, 142, 143
Palau	2	144, 145
Panama	2	268, 269
Philippines	13	146, 147, 148, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299
Seychelles	6	150, 151, 152, 153, 154, 300
Taiwan	14	155, 156, 157, 158, 159, 160, 161, 162, 301, 302, 303, 304, 305, 306
Tanzania	2	163, 164

differences (Fig. 1D). There was a higher percentage of sites with a low butterflyfish abundance in the Caribbean than the other two regions. The highest percentage of sites in the Indo-pacific was in the >4–6 fish per 100 m^2 class, whereas in the Red Sea, the peak number of sites was in the >6–8 fish per 100 m^2 class. Without baseline data from each area, it is difficult to judge whether these differences have been affected by reported high levels of fishing for the aquarium trade in the Indo-pacific and Caribbean. The number of species in the Caribbean and the Red Sea are 10 and 5 times lower than in the Indo-pacific (Fishbase 1.0 CD-ROM, eds. R. Froese and D. Pauly, 1994, ICLARM, Manila). Repeated surveys of reefs that are fully protected from fishing will be necessary to fully interpret these results.

Diadema sea urchins

High numbers of long-spined black sea urchins of the genus *Diadema* may be a secondary indicator of an imbalance in fish populations (McClanahan, 1995; Roberts, 1995; McClanahan *et al*., 1996). Like lobster, *Diadema* are nocturnal feeders, but are easily observed during the day. The results appear to indicate that *Diadema* populations are not high at most of the reefs surveyed (Fig. 1E).

Hard corals

The hard corals surveyed in this biased selection of 'best' sites were in better condition globally than fish and shellfish (Fig. 2). The mean percentage of living coral cover on reefs was 33% globally, with the Caribbean recording a significantly lower value (21%) than the other two regions ($p < 0.001$). These results match reports of serious declines in coral cover at a number of Caribbean sites in recent years (Hughes, 1994). The ratio of live to dead coral was significantly higher in the Red Sea than in the other two regions ($p < 0.001$), suggesting that these reef corals are amongst the healthiest in the world. The narrow range of regional means from some of the world's "best" sites calls into question the validity of the much higher coral cover values used previously to rate reef status (Luchavez and Alcala, 1988; Wilkinson *et al*., 1993; Munro and Munro, 1994; Grigg and Birkeland, 1997).

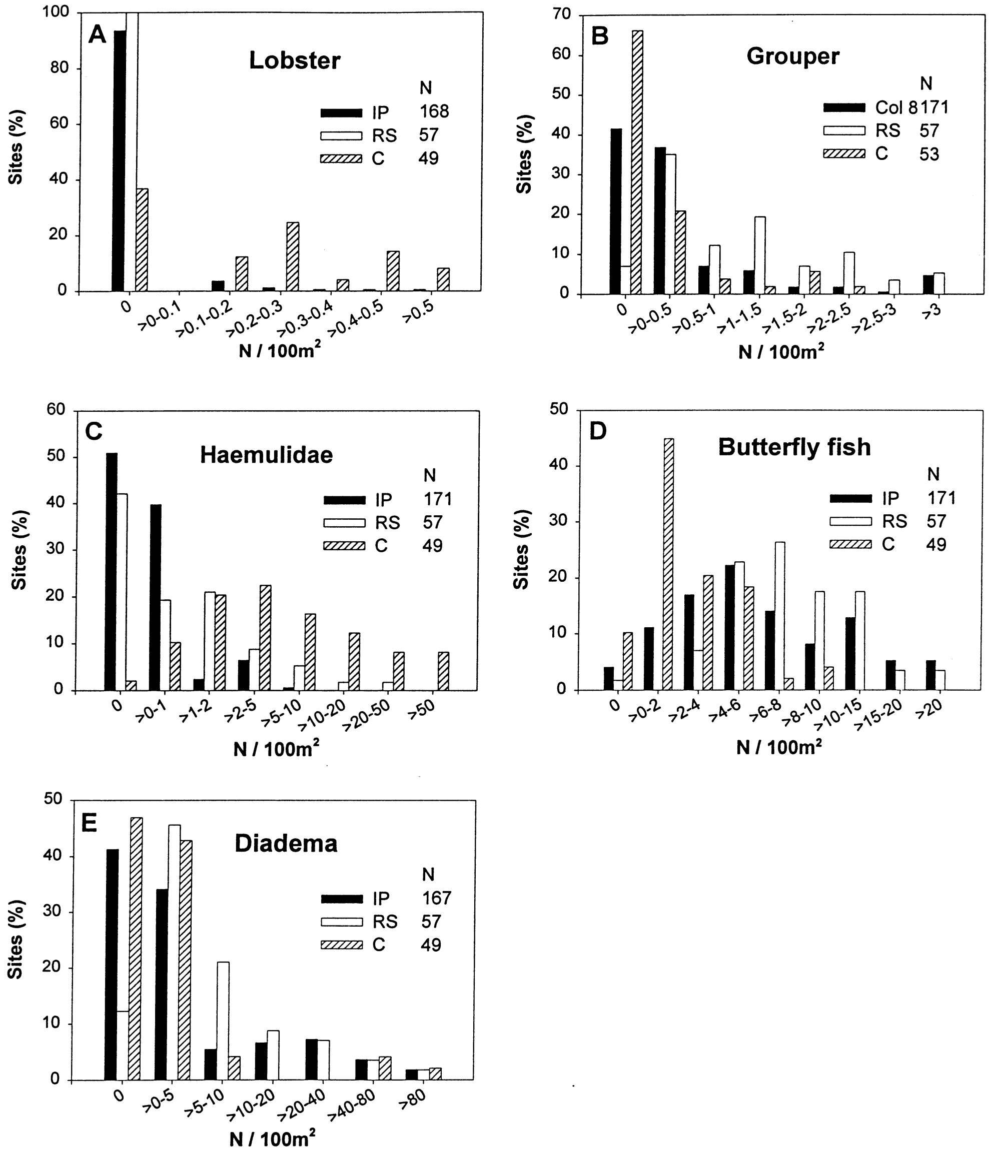

Fig. 1 Frequency distribution of sites among abundance classes of worldwide-indicator organisms in three regions (Indo-pacific (IP); Red Sea (RS); Caribbean (C)). Abundance classes are based on mean number of organisms from eight replicate 100 m^2 belt transect segments. Zero lobster (A) were recorded from over 90% of Indo-pacific sites, from almost 40% of Caribbean sites and 100% of Red Sea sites. (B) grouper, (C) Haemulidae, (D) butterflyfish, (E) *Diadema*.

Fleshy algae

Fleshy algae were chosen as an indicator of nutrient enrichment associated with sewage pollution. Most teams chose relatively unpolluted areas for their surveys, and only 18 sites showed greater than 10% cover of fleshy algae. Although herbivory, seasonality and other factors affect the level of fleshy algae on reefs, it is logical to conclude that nutrification due to sewage discharge is more important at reefs near urban areas which were not common in this study.

Sponges

On some reefs, a high abundance of encrusting sponges may indicate high nutrient levels or other problems (Wilkinson, 1987). The percentage cover of sponges was not found to be high at any sites. Less than 10% of sites in the Indo-pacific and Red Sea, and 30% of Caribbean sites had more than 5% encrusting sponge cover. This regional difference has been reported previously (Wilkinson, 1987).

Cluster analysis and ranking

Three additional analyses were carried out on the worldwide indicators. To examine relationships among all sites for six of the eight worldwide indicators (sponge and dead coral were excluded), a cluster analysis was run using the Bray-Curtis similarity index (Fig. 3). Software used was PRIMER (Plymouth Marine Labo-

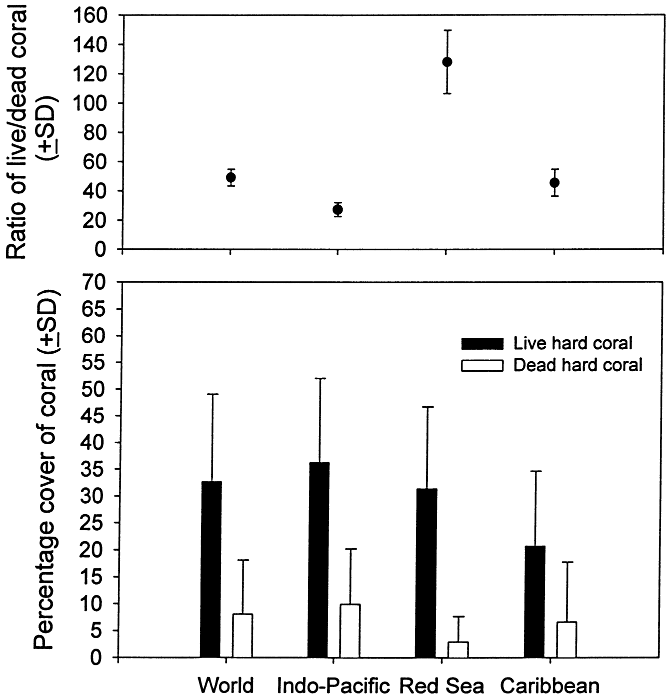

Fig. 2 World and regional results: (A) percentage cover of live and dead coral and (B) live:dead coral ratio.

ratory, UK). The abundance array was transformed using the Bray-Curtis similarity index and the dendrogram was constructed using the group-average linkage technique (see Clarke and Warwick, 1994). When "cut" at the 79% level, 17 clusters or groups are produced. By further ranking these groups in 3-levels of abundance, the results can be combined into nine sets of groups, each sharing a different set of characteristics (Fig. 3A–I). To rank the relative number of each organism recorded within a group, the mean abundance of a given organism at the 10 sites with the highest number of that organism was used as the maximum possible. This maximum value was divided in thirds and descriptors were assigned (bottom third = "very low, " middle third = "low," and upper third = "medium"). A separate set of mean values was calculated for each organism in each Group, and a descriptor applied. Groups sharing the same set of descriptors are shown together in Fig. 3A–I regardless of position in the dendrogram. These groups are not always adjacent to each other in the dendrogram due to the cluster algorithm placing sites with a "zero count" for a given organism in a different group from sites with a near-zero mean for that organism.

Shared characteristics

These sets represent a mixture of natural and anthropogenic differences among coral reefs in the three regions. The cluster analysis and ranking shows that most reefs share low numbers of indicator organisms on a global scale. The remaining reefs show similar abundance levels of globally distributed organisms on a regional scale. For example, the first set (Fig. 3A; Groups 1, 10, 14, 16 and 17) contains the most sites (167 or 55% of total) and includes sites from all three regions which share characteristics of 'very low' numbers of all indicators except hard coral. The second set (Fig. 3B) contains the three groups (2, 7 and 9) with the lowest abundance ranking 'very low' for all indicators, but only 6 sites are included and none from the Red Sea. Group 3 (Fig. 3C) comprises only two Caribbean sites which had 'medium' levels of haemulids. Groups 4–6 (Fig. 3D) are Caribbean sites (with one exception) characterized by 'very low' levels of all indicators except lobster which were 'low.' Group 8 (Fig. 3E) shares these characteristics but also has a 'low' rank for grouper. Of the 5 sites showing 'medium' levels of *Diadema* (Group 11) none were from the Red Sea. Group 12, which had the highest overall abundance only includes two sites (Fig. 3G). Together, Groups 13 and 15 (Fig. 3H and I) include 91 primarily Indo-Pacific sites featuring 'low' numbers of butterflyfish.

Coral reef health and distance-population index

To further examine relationships between the global results and other parameters, a Coral Reef Health Index (CRHI) and a Distance-Population Index were calculated. The CRHI was calculated using six of eight worldwide indicators (butterfly fish, haemulidae, grouper, *Diadema*, hard corals and lobster) for 269 sites from the 3 regions. The highest mean abundance of an organism recorded at any site in the world was used as a maximum possible value to determine a lower, middle

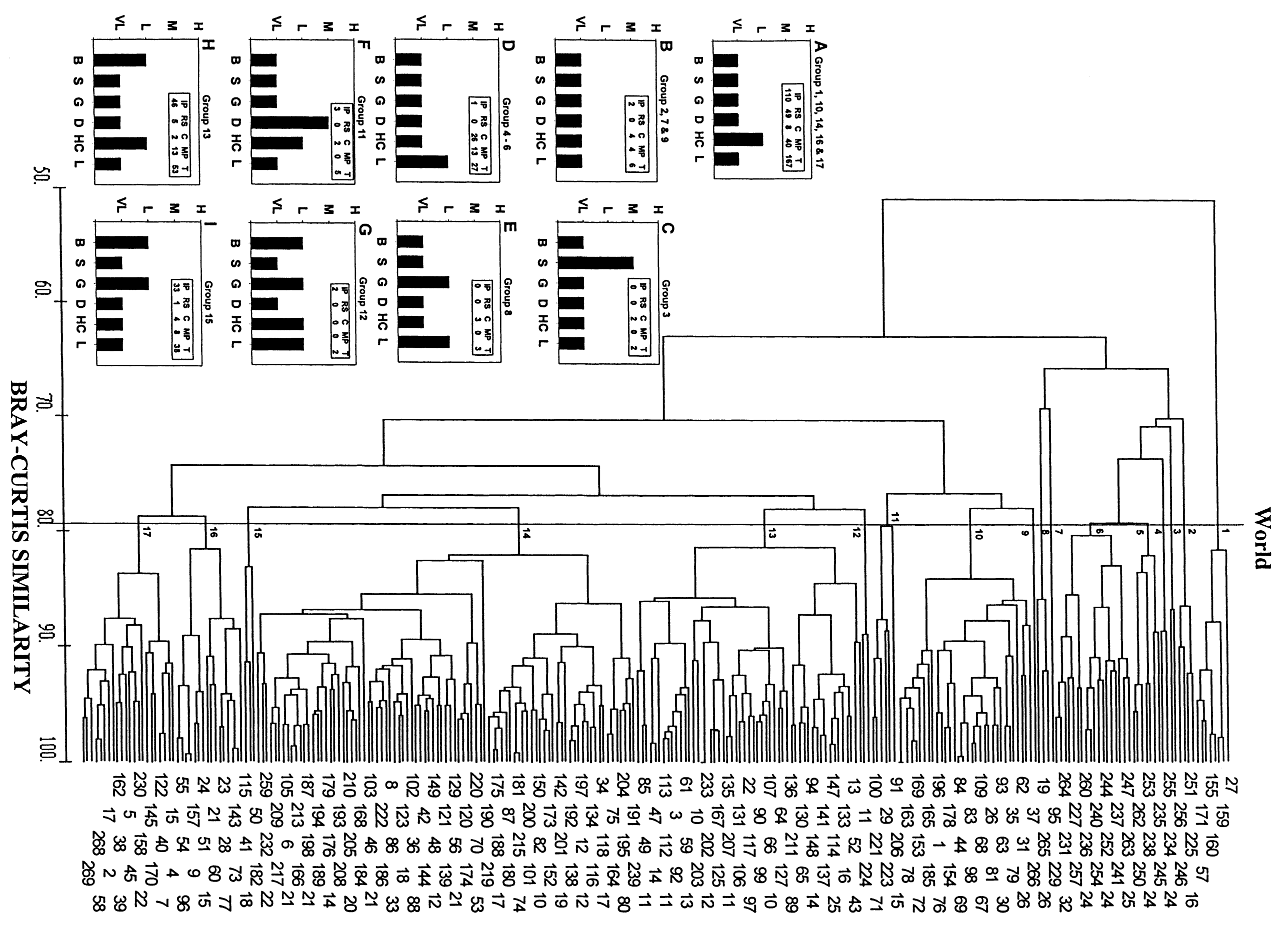

Fig. 3 Bray-Curtis similarity index dendrogram. Site numbers are shown adjacent to the branch tips and correspond to locations shown in Table 2. When 'cut' at the similarity level of 79, there are seventeen groups (numbers shown on cluster stems). These groups were further combined (see text) to create ranked abundance plots (small boxes A–I) Each box includes a set of groups that shares the same characteristics: On the *y*-axis, VL: Very Low, L: Low and M: Medium abundance. On the *x*-axis, B: Butterflyfish; G: Grouper; S: Sweetlips; D: *Diadema*; HC: Hard Coral and L: Lobster. In the inner boxes: the number of sites is given for IP: Indo-pacific; RS: Red Sea; C: Caribbean; MP: Marine Protected area; T: total number of sites in that set.

and upper third. Then, for each site, a value of 0–3 was assigned for each indicator depending on the level of the mean abundance in comparison to the cut-off levels for each third. Means in the lower, middle and upper third were assigned a value of 1, 2 or 3, respectively, while a mean of zero was assigned a zero (except for *Diadema* where the values were reversed as high numbers are considered to be unhealthy). The CRHI was calculated by adding the 6 values together. The maximum possible CRHI is: 6 indicators $\times 3 = 18$. The Distance Population Index (DPI) was calculated by assigning a score for both population of nearest city and the distance to that city as follows: Population 0 – 10,000 = 0; 10,000 – 50,000 = 1; 50,000 – 100,000 = 2; > 100,000 = 3. Distance > 50 km = 0; 25–49 km = 1; 10–24 km = 2; 0–9 km = 3. The DPI was then calculated as the sum of the population size and distance scores. The higher the index means the site is close to a dense population; maximum DPI is 6. The mean CRHI values were 3.8, 4.0 and 3.5, respectively, for the Indo-pacifc, Red Sea and Caribbean regions, out of a maximum possible CRHI of 18. There was no significant difference among the values from the three regions (Kruskal-Wallis ANOVA). The low CRHI scores are another indication of how few sites had high numbers of indicators recorded.

A plot of the CRHI values versus the DPI shows that all except three reefs (in Sabah) fall below the midpoint (MP in figure) CRHI of 9 (Fig. 4). While there is a significant correlation between the two indices ($r = 0.97$, $p < 0.001$), a sizable number of sites located far from population centers had a low health index. For example, most of the 50 sites surveyed along the unpopulated east coast of Borneo showed very low numbers of indicator organisms and evidence of serious damage due to blast fishing, apparently due to the activities of fishermen from other areas of Asia. This evidence contrasts with

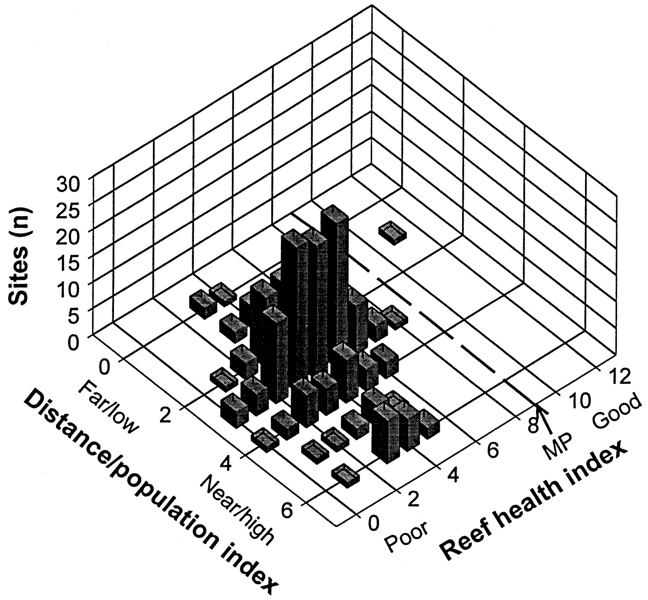

Fig. 4 Plot of Coral Reef Health Index vs. Distance-Population Index. Max CRHI = 18, MidPoint = 9

the consensus of the Miami Colloquium that reefs far from human populations were expected to be in better condition than those located near them.

Expected versus actual reef condition

All field teams were asked to make a subjective assessment of the level of overall impacts they believed were affecting their sites (none – high). When these assessments are plotted against the CRHI, the correlation ($r = 0.98$, $p < 0.001$) is high between real and perceived impacts (Fig. 5). However, it is important to note the many sites with a low CRHI (say, below 4) that team

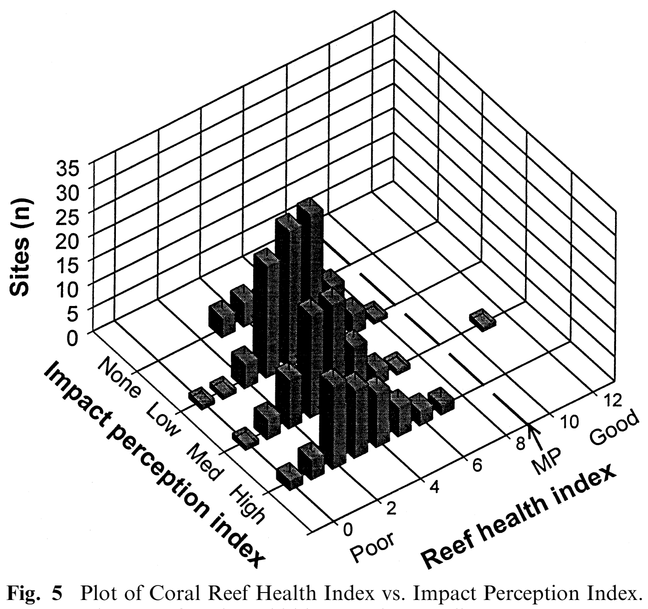

Fig. 5 Plot of Coral Reef Health Index vs. Impact Perception Index. There are five sites "hidden" at the coordinates: IPI = "none" and CRHI = 5 or 6.

leaders rated as experiencing low to medium impacts. This comparison could indicate that anthropogenic impacts are more common and more serious than experienced observers expected. One explanation is that human activities such as seasonal or night-time fishing, which may have long-lasting effects, are not generally observed.

Indo-pacific and Red Sea fish

Examining the results for the Indo-pacific and Red Sea, humphead wrasse and barramundi cod were absent from 86% and 98%, respectively, of 171 reefs surveyed (Fig. 6A and B). Of more than 25 km of Indo-pacific reef surveyed, only 46 humphead wrasse were seen. At the 124 Asian and Australian reefs surveyed, only 3 barramundi cod were recorded. These results suggest that cyanide and other forms of fishing that target these species have severely reduced populations of these once moderately abundant species (Johannes and Riepen, 1995). The results for the bumphead parrotfish were similar (Fig. 6C), with no fish recorded at 67% of sites. Sightings of the parrotfish and wrasse were included in the count even when they were outside the transect as these fish are known to roam among reefs rather than being resident. On a recent survey of four remote reefs in Vietnam I recorded up to 9 bumpheads of >0.5 m length on one reef and at least two large specimens on each of the other reefs, giving some indication of where the baseline level ought to be.

Sea cucumbers, giant clams and tritons

High-value, edible sea cucumbers were previously common on the seabed around many Indo-Pacific reefs, but have been subjected to over 100 yr of intensive harvesting. The four species included in this survey were totally absent from 39% of Indo-pacific reefs surveyed and few were found at the other sites (Fig. 6D). A mean of 11 giant clams (*Tridacna* spp.) was found on Indo-pacific reefs. An indication of the potential maximum size of natural populations is provided by the 150–250 giant clams recorded at several protected sites in the Red Sea and Australia (Fig. 6E). The triton shell, which is attractive to shell collectors, was absent from 90% of the reefs surveyed. It is unknown whether this animal was ever common before trade in shells became a global industry.

Crown-of-thorns sea stars

A relationship between human activities and periodic outbreaks of the Crown-of-thorns sea star (COTS) (*Acanthaster planci*), has been suggested (Birkeland, 1982). The results show that low numbers of COTS were recorded in both the Indo-pacific and Red Sea in 1997 (Fig. 6F).

Caribbean fish

The results for parrotfish in the Caribbean are similar to those for butterflyfish, with a peak at 2–5 fish per 100

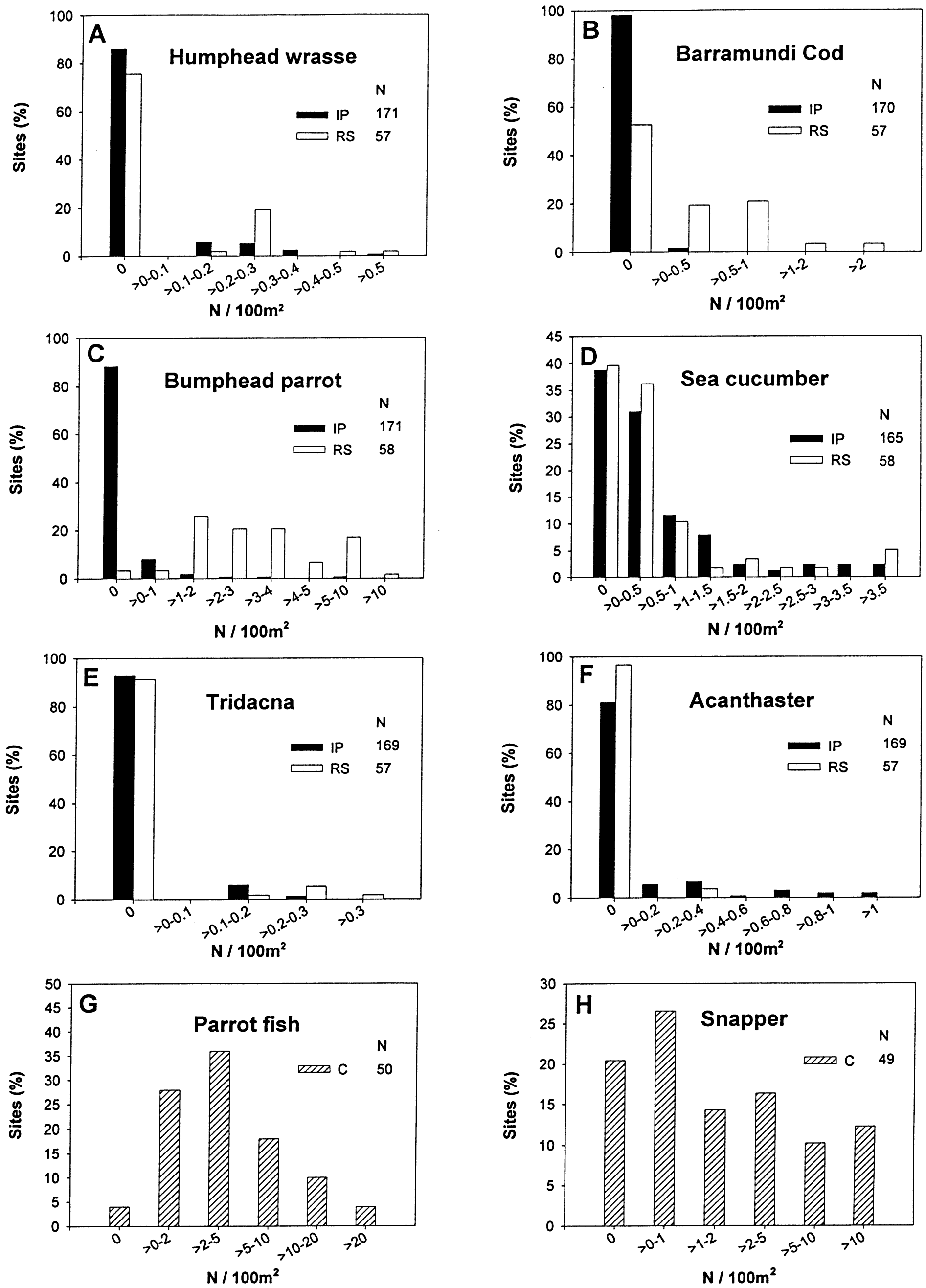

Fig. 6 Frequency distribution of sites among abundance classes of regional indicator organisms. Indo-pacific indicators: (A) Humphead wrasse, (B) Barramundi cod, (C) Bumphead parrotfish, (D) Sea cucumbers, (E) *Tridacna*, (F) Crown-of-thorns; Caribbean indicators: (G) Parrot fish, (H) Snapper.

m^2 (Fig. 6G). In contrast, there was a relatively even distribution of numbers of sites among different abundance classes of snapper (Fig. 6H).

Hong Kong reefs

Hong Kong provides an example of coral reefs subjected to almost every form of disturbance. Even the "best" reefs are subjected to overfishing, poison and blast fishing, pollution and sedimentation (Hodgson, 1997). Out of 11 collectible or edible indicator species, only two (*Trochus* shells and butterflyfish) were recorded. Several of these once-abundant organisms including commercial species of lobster now appear to be effectively extinct in Hong Kong. The change has been rapid. A published photograph taken in 1976 shows a catch of over 20 lobster following an hour's dive in Clearwater Bay, Hong Kong (Wong, 1996).

Conclusions

A global coral reef survey program called Reef Check was successfully tested in 1997. The goal of a synoptic survey using a single method during a short period at many sites around the world was achieved, but there are several limitations to the program. While the sites covered a far larger geographic area than any previous survey, there are still about 70 countries with coral reefs where no surveys were made. More importantly, the sample size of over 300 sites is tiny in comparison to the several thousand sites that should ideally be surveyed annually such that both local and regional interpretations could be made of coral reef health. From a global perspective, the Red Sea was over-represented in this survey while the Caribbean was under-represented. In future years, by increasing the number of reefs and frequency of surveys, the Reef Check program could provide a valuable method to detect broad-brush changes on a local, regional and global scale, as well as increasing public support for coral reef conservation. The survey results could be useful for evaluating the success or failure of management efforts.

Overfishing

No reefs showed high numbers of most indicator organisms, suggesting that few if any reefs have been unaffected by fishing and gathering. The survey was biased, by design, towards sites in good condition, hence far from cities and pollution sources, and the low percentage cover of pollution indicators (sponges and fleshy algae) suggest that sewage pollution is not a serious problem at most of these sites. Taken together with the conclusions on overfishing, these results could indicate that previous views regarding human impacts on reefs on a global scale may have unduly emphasized the importance of pollution in comparison to overfishing (Johannes, 1975). Stated another way, most of the world's reefs are not located near cities, therefore sewage and industrial pollution are unlikely to strongly affect most reefs. Overfishing of key fish species, in addition to reducing their numbers, can lead to a physical breakdown of the coral reef system (McClanahan, 1995; Roberts, 1995; McClanahan *et al.*, 1996).

Shifting baseline syndrome

The greatest difficulty in interpreting this data set is the "shifting baseline syndrome" (Froese and Pauly, 1994, Sheppard, 1995). There are few quantitative data describing what populations of reef organisms were like before widespread fishing. In general, changes that occur over a human life span are recognized, and reported at least anecdotally, by fisherman or divers. But when changes have occurred over several hundred years, the pristine baseline, which could be more than one order of magnitude higher than present numbers, is difficult to estimate. For example, Jackson (1997) has provided strong evidence that fish populations in Jamaica were already decimated over 100 yr ago and he suggests that this situation is common. He also suggested that no true pristine reefs remain because, in addition to widespread fishing, populations of large herbivores such as turtles, dugongs and manatees, which would strongly influence coral reef ecology, were historically much higher than they are today.

To interpret the global survey data in lieu of a baseline, it has been assumed that the highest numbers of animals recorded reflect what the baseline ought to be. This is the basis for the CRHI. If this assumption is valid, the results suggest that demand is far outpacing supply of high-value, edible and collectible species, and that over harvesting has reduced populations to low levels on shallow reefs throughout the world. The biological reasons for why it is so easy to "fish out" coral reefs have been explained by Birkeland (1997), who has recommended that no commercial harvesting for export be allowed on any reefs.

Marine parks

In recent years, numerous marine protected areas have been set up around the world, but unfortunately many of these are "paper parks" with little effective management (Hodgson, 1992). Illegal fishing inside marine parks has been documented even in well-managed reserves such as the Great Barrier Reef Marine Park (Gribble and Robertson, 1998). When the mean CRHI from sites located inside marine protected areas (CRHI $= 3.7$, $n = 72$) was compared with the mean for non-protected sites (CRHI $= 3.8$, $n = 197$), there was no significant difference (*t*-test). This finding indicates that on average, either management is not effective, or that there has been insufficient time for management to increase populations of indicator organisms. The CRHI is a composite index, therefore the relatively high numbers of organisms recorded for a few individual species at some marine parks, is not sufficient to give these sites a high CRHI. The survey results are a snapshot in time, and for this and other important questions, they point to a critical need for more detailed stock assessments and application of standard fishery models to determine how far populations of reef fish and invertebrate species have been reduced and why.

Solutions

The first step in solving the problems documented by this survey is to acknowledge the fact that a serious global crisis is facing some coral reef organisms, and thus coral reef health. Actions that can be taken include tighter control of fishing through traditional as well as newer methods e.g. international satellite monitoring of fishing boat movements; substantially increasing the number and size of marine protected areas and improving their management so that they can serve as 'seedbeds' for surrounding areas (Johannes, 1998); expanding research and testing of aquaculture of high-value reef species to meet the growing demand for sea-food and other products that coral reefs will never be able to supply; using education and legislation to reduce demand for cyanide-caught live fish, particularly large animals that have a high value for dive tourism and that contribute greatly to reproduction. Finally, participation in the Reef Check program is one solution as it increases public awareness about the value of coral reefs and threats to their health. Funding agencies, political leaders and natural resource managers need to focus on implementing these achievable solutions now.

I thank S. Geermans, T. Fong, K. Kei and T. Cheung for data management, producing graphics and statistical tests. I gratefully acknowledge the sponsorship of hundreds of businesses, universities, government agencies, NGOs and individuals around the world, and the National and Regional Coordinators, Team Scientists and Leaders (listed below) and over 750 participants in the Reef Check 97 global survey program, who voluntarily spent their time and money to produce the results analyzed in this paper. I thank many scientists who offered advice on designing the 'perfect' survey and C. Birkeland, R. Kinzie, W. Hamner and C. Wilkinson for comments on the manuscript. Special thanks to our informal scientific committee of M. Milicich, J. Lang and R. Grigg, to R. Ginsburg for getting it all started, to J. Chen for financial support through HKUST and G. Heinke for providing a home at the Institute. Reef Check scientists and leaders were: M. Abe, T. Adami, L. Adhyasko, E. Arias, R. Aryasari, R. Berkelmans, J. Breman, D. Byron, J.C. Chang, M.S. Cheng, C.H. Chung, R. Claro, L. Colin, A Cornish, P. Crevello, A. DarbyshireA, C. Davies, S. Dorsey, A. Dunstan, M. Eisinger, U. Ertfurth, H. Evans, J. Feingold, N. Galvis, G. Garcia, M. Gektidis, L. Goh, R. Gomez, F. Grothe, A. Gruber, M. Guard, J. Guest, A. Haas, C. Hall, A. Harborne, B. Haskell, M. Hassan, G. Heiss, T. Hodson, I. Horsfall, C. Hunter, S.T. Hwang, D. Hyde, T. Iliffe, T. Itou, E. Karath, S. Kegeles, C. Kievman, J. Lang G. Lilley, C.K. Loh, V. Lubini, J. Lun, H. Malcolm, D. Martinelli, J. Massey, D. McCorry, K. De Meyer, T. Moore, R. Murphy, B. Neill, N. Noya, S. Oakley, J. Olds, J. Oliver, M. Page, S. Pasaribu, C. Petrovic, J. Phipps, N. Pilcher, I. Popple, A. Put, K. Putra, N. Quinn, A. Rahmat, M. Roberts, S. Romano, A. Salih, H. Schielly, S. Searcy G. Setyadi, M. Short, K. Soong, A. Stone, R. Thorn, G. Usher, R. Uwate, V. Vahrenkamp, H. Vicentini, D. Wachenfeld, U. Waeber, L. Wantiez, A. White, M. Whittington, I.W. Widjatmoko, K. Wilson, G. Woerheide, E. Wood, H. Zahir, P. Ziegler.

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